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Identifying climate service production constraints to adaptation decision-making in Sweden

Kathleen M. Ernst[a,1], Åsa Gerger Swartling[b], Karin André[b], Benjamin L. Preston[c], Richard J.T. Klein[b,d,e]

[a] Bredesen Center for Interdisciplinary Graduate Education, University of Tennessee, Knoxville, Tennessee, USA
[b] Stockholm Environment Institute, Stockholm, Sweden
[c] Community Health and Environmental Policy Program, RAND Corporation, Santa Monica, California, USA
[d] Global Center on Adaptation, Rotterdam and Groningen, The Netherlands
[e] Linköping University, Sweden

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ABSTRACT

Climate change adaptation efforts continue to increase as the impacts of climate change increase, intensify, and become more apparent. However, many adaptation efforts fail to result in adaptation actions. This inaction has been linked to several constraining factors including a lack of actionable information for adaptation decision-making processes. We wonder if climate service producers face constraints as they try to create and deliver actionable information for adaptation decision-making efforts? This paper draws on semi-structured interviews and participant-observations across climate service production environments in Sweden to answer our research question and finds that climate service producers engage in research, coordination, and communication to varying degrees and experience constraints related to the production and dissemination of actionable information and stakeholder engagement, as well as funding, professional, and institutional constraints. Some constraints are experienced differently by climate service producers depending on their specific role, institutional affiliation, agency, and experience. Additionally, some climate service production constraints create or exacerbate additional constraints for adaptation decision-making stakeholders. Therefore, climate service production constraints limit the effectiveness of climate services, and overcoming them would help make progress towards more adaptation implementation in specific contexts. However, for adaptation actions to be widespread, the production and dissemination of climate services must be met with additional support and guidance for adaptation efforts beyond the provision of actionable information.

1. Introduction

Climate change is increasingly apparent, as are the losses and damages related to its impacts (IPCC, 2014; Melillo et al., 2014; Mimura et al., 2014). When these consequences are coupled with the current growth of fossil fuel emissions (Friedlingstein et al., 2010; Preston et al., 2013), the pursuit of adaptation to avoid adverse outcomes is both a present necessity and a substantial future challenge.

Climate change adaptation (referred to hereafter as 'adaptation') efforts have increased, particularly over the past decade, but many of these efforts have struggled to implement tangible adaptation actions (Lesnikowski et al., 2013, 2011; Mimura et al., 2014; Woodruff and Stults, 2016). Several reasons have been provided in peer-reviewed literature for this phenomenon including, but not limited to, a lack of requirements, policies, guidance, support, trust, and actionable information for adaptation decision-making processes (Amundsen et al., 2010; Bierbaum et al., 2013; Biesbroek et al., 2011; Ekstrom and Moser, 2014; Jantarasami et al., 2010; Jones and Boyd, 2011; McNamara et al., 2012; Moser and Ekstrom, 2010; Storbjörk, 2010). An ongoing question in the adaptation discourse is the extent to which the widespread perception among decision-makers of the inability to appropriately resource adaptation efforts is an inherent limit to adaptation or simply an inconvenient constraint that can be overcome.

Of the various constraints on adaptation that have been described, a lack of actionable information is one of the most common (Cash et al., 2003; de Bremond et al., 2014; Dilling and Lemos, 2011; Kirchhoff et al., 2013; Liu et al., 2008; Vaughan et al., 2016; Wall et al., 2017), despite the now widespread, and growing, availability of climate

E-mail address: kassie@vols.utk.edu (K.M. Ernst).
[1] Permanent address: NOAA RESTORE Science Program, NOAA / NCEI 1021 Balch Blvd., Suite 1003, 39529, Stennis Space Center, MS, United States.

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knowledge (Lesnikowski et al., 2011; Porter et al., 2015). While knowledge and information are often assumed to be beneficial to decision-making processes, when that information is not actionable, it can impede, rather than facilitate, decision-making (de Bremond et al., 2014; Nordgren et al., 2016). For example, information can be too general, or too focused on a single sector (Amundsen et al., 2010; Cash and Moser, 2000; de Bremond et al., 2014; Nordgren et al., 2016; Storbjörk, 2010); or it may require tailoring, interpretation, or integration with other information before it can be useful (de Bremond et al., 2014; Dilling and Lemos, 2011; Feldman and Ingram, 2009; Klein and Juhola, 2014; Meerow and Stults, 2016; Preston, 2013; Preston et al., 2015b). Alternatively, actionable information, or information developed at decision-relevant scales that coordinates many factors, options, and driving forces with iterative stakeholder input (Bierbaum et al., 2013; de Bremond et al., 2014; Lemos et al., 2012; Liu et al., 2007) is recognized as an enabling factor for sustainable development (Barnett and O'Neill, 2010; Bierbaum et al., 2013; Cash et al., 2003; de Bremond et al., 2014; Dilling and Lemos, 2011; Lemos et al., 2012; Magnan and Ribera, 2016). Some studies have pushed back on the notion that climate information and its availability are such pervasive barriers to adaptation citing adequate amounts of climate information and an increased understanding of future changes among decision-makers – instead, these information-related barriers highlight a lack of guidelines, resources, and support for taking adaptation actions (Porter et al., 2015).

Adaptation decision-making research tends to focus on interactions between stakeholders (Adger et al., 2009; Moss, 2016; O'Brien and Wolf, 2010; Vulturius and Gerger Swartling, 2015), the type of information decision-makers need (Cash et al., 2003; Dilling and Lemos, 2011; Meadow et al., 2015; Muñoz-Erickson et al., 2017; Vincent et al., 2017), and the contexts and processes of decision-making (Adger et al., 2003). Much less research has taken a direct approach to analyzing the contexts and processes of knowledge production (Miller et al., 2018) or the constraints that knowledge producers face as they endeavor to create and effectively disseminate actionable information for adaptation decision-making. This study is placed within this knowledge production analysis gap and is therefore not focused on decision-makers. Instead, this study is concerned with the processes, contexts, institutions, and actors that produce knowledge for adaptation decision-makers.

In this paper, we seek to understand the factors that hinder the development of effective climate services for adaptation decision-making at urban and regional scales by examining the production of climate services in Sweden. Specifically, the guiding question we endeavor to answer with this study is: **What constraints do climate service producers in Sweden face in effectively producing and delivering actionable information for adaptation decision-making?** We consider how climate service producers generate, translate, and communicate information for decision-makers focused on urban planning, energy and water management, hazard and risk management, and outdoor recreational management; and what factors influence their processes, decisions, priorities, and actions. We draw on semi-structured interviews with climate service producers in Sweden and participant-observations in Swedish climate service production contexts to answer our research question.

2. Reflexive climate services analysis

Climate services endeavor "to provide people and organizations with timely, tailored climate-related knowledge and information that they can use to reduce climate-related losses and enhance benefits, including the protection of lives, livelihoods, and property" (Vaughan and Dessai, 2014, p. 588). Interest in climate services has grown over the past decade, particularly after 2009 when the 3rd World Climate Conference endorsed a "Global Framework for Climate Services", however climate-related research endeavors created to inform decision-makers like climate services have been produced for over a century (Vaughan and Dessai, 2014). We broadly conceptualize these research developments that are inclusive of climate services as 'climate knowledge systems' in an effort to connect to past and future developments of climate knowledge, and to highlight the commonalities that connect them.

Knowledge systems encompass the accepted knowledge used in decision-making (Silva and Stocker, 2018). The seminal work on "knowledge systems for sustainability" by Cash et al. avoided a concrete definition of knowledge systems, but stated they could be individual tools, worksheets, models, and assessments designed to harness science and technology to link knowledge to action (2003, p. 8087). Knowledge systems can also be more complex by integrating multiple systems together (Cash et al., 2003; Miller et al., 2010; O'Brien, 2012). Miller et al. presents a definition of a knowledge system "as a suite of interconnected individual, social, and/or institutional practices by which knowledge claims get formulated…validated, circulated, and put to use in making decisions" (2010, p. 2). Since decision-making and knowledge-making occur within social contexts with pre-existing power structures and inequalities, some types of knowledge are typically included within knowledge systems, while others are not (e.g. linear, reductionist, mechanistic knowledges are more often included in decision-making contexts while complex, pluralistic, and traditional ecological knowledges are not) (Bremer and Glavovic, 2013; McNamara et al., 2012; Silva and Stocker, 2018). These power structures can reinforce the incorrect notion that some possess knowledge while others simply need exposure to that knowledge to make sound decisions (Miller et al., 2010, p. 4). Additionally, pre-existing social contexts and power relations in knowledge systems create and reinforce the conditions and outcomes of governance, the framing of the questions being asked, the methodologies used, the actors who participate, how assumptions are defined, and how uncertainty is dealt with in decision-making processes (Muñoz-Erickson et al., 2017). We acknowledge these elements of knowledge systems in our theoretical framing of climate services production analysis.

The theoretical framing for this study examines actors, institutions, and processes of the climate services production process by combining "thick", actor-oriented, and reflexive research approaches to analyze the production of climate services in Sweden (Adger et al., 2003; Klein and Juhola, 2014; Preston et al., 2015c). Adger et al.'s "thick" environmental decision-making analysis (2003), built upon Geertz's "thick" description theory (1973), examines actors, institutions, and processes to enable generalizability while also recognizing the importance of context. Through this lens, climate service production processes (and their associated actors and institutions) are conceptualized, and investigated as, parts of the adaptation decision-making process.

Next, we focused on the roles, responsibilities, and agency of climate service producers and institutions based upon actor-oriented and reflexive approaches to adaptation research (Klein and Juhola, 2014; Preston et al., 2015c). These approaches highlight the facilitative roles that climate service producers play within adaptation decision-making processes, and the importance of considering their agency which has hardly been discussed in peer-reviewed literature to date (Klein and Juhola, 2014; Preston et al., 2015a, 2015c).

If one seeks to improve the design of climate services, it is also important to engage the emerging reflexivity within adaptation research and practice. Adaptation is not yet well understood, and more scrutiny and critical reflections are necessary to move the burgeoning field forward (Preston et al., 2015c). Preston et al. (2015c) emphasize that adaptation is not inherently beneficial and that researchers should seek to understand how decisions can be made with social legitimacy and ethical considerations enabling the inclusion of more perspectives and knowledge forms to enhance the usefulness of adaptation processes. Without reflexivity in adaptation research, the limitations of existing climate services, methodologies, and adaptation decision-

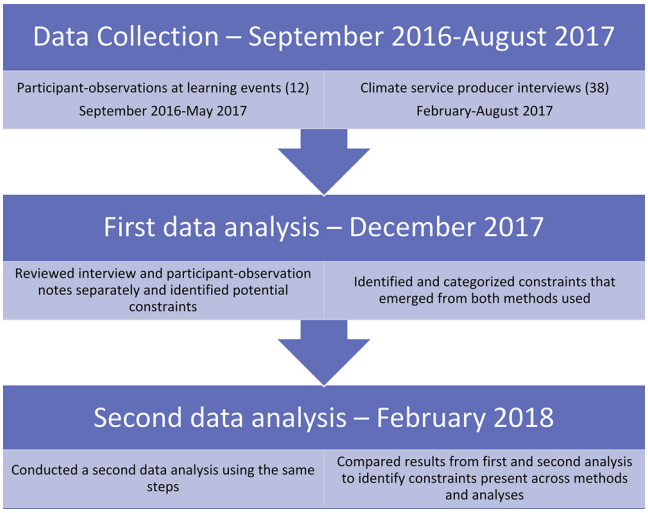
Data Collection – September 2016-August 2017
Participant-observations at learning events (12)
September 2016-May 2017
Climate service producer interviews (38)
February-August 2017
First data analysis – December 2017
Reviewed interview and participant-observation notes separately and identified potential constraints
Identified and categorized constraints that emerged from both methods used
Second data analysis – February 2018
Conducted a second data analysis using the same steps
Compared results from first and second analysis to identify constraints present across methods and analyses

Fig. 1. A timeline of the methods used and analyses conducted for this study.

making processes may go unrecognized.

3. Methods

We combined "thick", actor-oriented, and reflexive theoretical approaches to investigate climate service producers and production environments in Sweden. Sweden was chosen as the primary focus of our study to provide a similar national context across institutions, because national and international adaptation-focused institutes in Sweden are co-located, and because Sweden is recognized as a leader in climate services production (Massey et al., 2015). Data were collected between September 2016 and August 2017 at twelve distinct "learning events" (conferences, workshops, seminars, and meetings) throughout Sweden, and in climate service producer work environments at the Swedish Meteorological and Hydrological Institute (SMHI) which encompasses both research and consulting activities and houses the Rossby Centre (focused on climate science), the Coordinated Regional Climate Downscaling Experiment International Project Office, and the Swedish National Knowledge Centre for Climate Change Adaptation.

We conducted semi-structured interviews and participant-observations to obtain data on the perspectives and agency of climate service producers; and on the processes of climate service production (See Fig. 1 for an overview of the methods and analyses conducted). Semi-structured interviews are designed to be flexible and to engage interview subjects, and may lead to insights that are not discussed or observed within a group (Rubin and Rubin, 2012). Participant-observations are designed to increase familiarity with actors by partaking in their environment which increases rapport and also enables first-hand observations of nuances and/or contextual details that are hard for subjects to articulate or even acknowledge (DeWalt and DeWalt, 2011; Kitchin and Tate, 2013). Anytime participant-observation was conducted at learning events, the participant-observer[2] was introduced and briefly explained the purpose of the observation. The participant-observer took field notes during learning events and recorded a summary of observations after each event ended.

In total, 38 semi-structured interviews were used for this study. Interviews lasted between 15 and 90 minutes, with most interviews averaging approximately 45 minutes. Interview subjects worked across 21 institutions in Sweden (most with multiple institutional affiliations), and were identified through their participation in a learning event or through the snowball sampling method (Hay, 2000). Climate service producers were asked similar questions about experiences, roles, and constraints related to creating or disseminating climate services, but interview subjects had agency over the direction of semi-structured interviews and specific constraints were brought up by the participants themselves, not the interviewer. Since questions varied across interviews, specific numbers or percentages of participant responses are not identified in the results.

Semi-structured interviews were conducted in both Swedish and English. We decided that if English was used as a primary language in a professional setting, that the participant could be interviewed in English. It is worth noting that some climate service producers in Sweden have varying levels of Swedish proficiency and use English as their primary language in Sweden. Each participant knew ahead of time if an interview would be conducted in English, and English was only used for a semi-structured interview if it was used as a primary professional language by participants. While misinterpretations can still occur, our methods aim to minimize them. No direct quotes are attributed to any single participant to avoid misinterpretation and over-generalization of a single participant's experience. Second, only general constraints are identified in this study – any constraint identified in the results was brought up by multiple participants and emerged as a theme across the data. These efforts increase rigor while also minimizing any risk of misinterpretation.

We used two qualitative methods in twelve learning events that involved multiple participants to triangulate our data and identify consistent findings. Data triangulation strengthens the credibility of qualitative studies by combining multiple methods, perspectives, and sources to investigate research questions and uncover generalizable or transferable observations across the methods used, cases studied, and subjects interviewed (Baxter and Eyles, 1997). We recognize that some findings from our study may be generalized across many contexts. Data triangulation helps identify those generalizations by ensuring that findings are robust (i.e. consistently present across the cases, methods, and subjects analyzed).

We analyzed interview data first, by reviewing all interview notes and highlighting any instances that identified constraints to climate service production. Then we iteratively grouped the identified constraints based on topics that emerged within the data. Next, we reviewed participant-observation data, identified climate service production and dissemination constraints, and iteratively grouped these constraints together based on topics that emerged across the data. Then, we created a document that included constraints that were consistently identified across interview and participant-observation data. This first review was completed by December 2017. We conducted a second review of the data in February of 2018 using the same analytical steps. After both reviews were complete, we compared the first and second analysis documents to identify climate service production constraints that were consistently identified across methods and analyses. The results are discussed next.

4. Results

Every climate service producer interviewed for this study played a unique role that combined research, coordination, and communication of knowledge for adaptation decision-making. Fig. 2 was created by the authors to depict the primary roles of the climate service producers interviewed for this study on a spectrum of climate service production. The Climate Service Production (CSP) Spectrum categorizes the climate service producers interviewed for this study by the predominate roles they play across projects. Climate service producers on the production side of the spectrum (referred to hereafter as 'researchers') predominately create new knowledge and information that serve as climate service inputs; and develop and disseminate climate services to stakeholders. Climate service producers on the intermediary side of the spectrum (referred to hereafter and elsewhere as 'intermediaries' (Jacobs et al., 2005; Vogel et al., 2007)) predominately add supporting

[2] The corresponding author conducted all participant observations for this study. No participants objected to observations during the study.

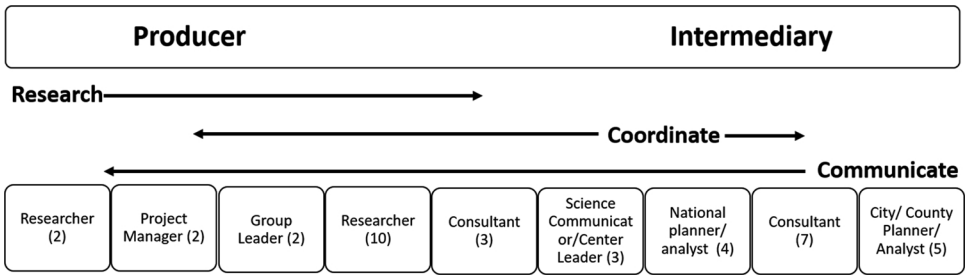

Fig. 2. The Climate Service Production (CSP) Spectrum visualizes the roles and activities of climate service producers interviewed for this study. Research, coordination, and communication activities vary across the CSP spectrum, but are emphasized where indicated. Numbers in parenthesis indicate the number of subjects interviewed. Interview subjects were uniquely varied across the spectrum, but categories were organized for clarity.

Table 1
Climate service production constraints to adaptation decision-making.

Constraint	Examples	Identified by	Producers most affected
Production constraints			
Modeling complexities, data issues, knowledge gaps or limits	Complicated modeling processes	Researchers	All
	Sub-city modeling/analysis new in most disciplines	Researchers	All
	Knowledge continuously updating/changing	Intermediaries	Intermediaries
	Unmapped, uncoordinated, unorganized data	Intermediaries	Intermediaries
	Lack of data, particularly for smaller localities	All	All
	Knowledge gaps	All	All
Policy and regulatory uncertainty (especially regarding climate change)	Compounds modeling uncertainties	Intermediaries	All
	Hard to collaborate beyond discipline/focus	Intermediaries	All
	Difficult to discern roles/responsibilities	Intermediaries	Intermediaries
Dissemination constraints			
Interpretation and representation of context within services	Hard to make scenarios contextual	Intermediaries	All
	Development/communication of data has improved, interpretation has not (unclear what the data means, how to use/integrate it)	Intermediaries	All
	Unmet demand for non-existent/higher resolution data at decision-relevant scales	All	All
Stakeholder realities, needs, context	Experience/perception that decision-makers want simplicity	All	All
	Lack of knowledge about decision-making contexts	Mostly researchers	All
Mismatched consideration, understanding, and concepts of uncertainty	Decision-makers want clarity (i.e. minimal uncertainty) to inform decision-making, and researchers want to identify/detail uncertainties to inform science	Mostly researchers	Mostly researchers
	The multiple concepts and types of uncertainty are hard to explain and reconcile	All	All
	Difficult to explain uncertainties within a climate service and satisfy stakeholders	All	All
	Policy/decision-making/societal uncertainties compound uncertainty for climate service producers, which is not communicated to decision-makers	All	All
Stakeholder engagement constraints			
Expectations	Stakeholder fatigue	Researchers	All
	Stakeholder disappointment	Researchers	All
Time	Stakeholder identification	Researchers	Researchers
	Tailoring information	Researchers	All
	Stakeholder engagement	Mostly researchers	Mostly researchers
Funding, professional, and institutional constraints			
Funding	Increasing/unsustainable proportion of project-based funding	Mostly researchers	Mostly researchers
	Balancing funding expectations/deliverables	Researchers	All
Roles	Balancing roles between researchers and consultants	Mostly researchers	Mostly researchers
Prestige	Perception that (others think) climate services work is not prestigious	Mostly researchers	Mostly researchers
	Perception that researcher commitment is lacking due to a perceived lack of prestige	Intermediaries	All

information or synthesize data to explain how a location may be impacted; and package and communicate climate services to stakeholders.

The CSP Spectrum adds context to the climate service production and dissemination constraints that are detailed in Table 1. Some constraints were predominately identified by intermediaries or researchers, but could affect others as well. A few constraints only affect researchers or intermediaries. In some cases, a constraint that emerged on one side of the spectrum created or exacerbated an additional, but separate constraint on the other side of the spectrum. Constraints in Table 1 are organized into four categories and detailed next.

4.1. Production constraints

Knowledge production constraints concerned challenges related to creating actionable information for adaptation decision-making. Specifically, climate service producers noted that modeling processes were complicated, and that some data refinement was difficult to produce. Some intermediaries noted that the constant updating of information, specifically climate information from researchers, made translating and communicating information difficult.

Similarly, some decision-relevant data (not only climate data) was uncoordinated or unorganized, lacking in quality, or did not exist which hindered climate services production. For some researchers, land-use maps were not refined enough for modeling demands. For some intermediaries, information required for their models lacked guidance about how it was derived and how the results might influence other processes. Other climate service producers knew that stakeholders wanted climate information with refined spatial and temporal resolution, but that obtaining that resolution would be time- and resource-intensive, and may not yield more clarity.

One constraint predominately identified by intermediaries, but present across the CSP Spectrum is the lack of national and/or European Union guidelines for addressing climate change. Uncertainty regarding how decision-makers and society will react to, mitigate, and plan for future changes compounds uncertainty within modeling processes. Climate services that produce future projections typically consider potential adaptation options, mitigation pathways, and the effects that these changes will have. When little certainty about what those options might be exists, more uncertainty is embedded within climate services. One researcher noted that he could model the processes that influence sea-level rise, but he was uncertain about the extent of change to expect because of uncertainty regarding how society and decision-makers will act.

4.2. Dissemination constraints

Knowledge dissemination constraints concern the applicability, communication, and uptake of climate services. These constraints focus on interpreting climate-related information, understanding stakeholder decision-making environments, and effectively communicating uncertainties within climate services.

Some climate service producers lacked knowledge of adaptation decision-making realities. In some cases, climate service producers created a climate service that was difficult, or even impossible, to integrate into decision-making platforms or frameworks. In others, climate service producers did not connect with stakeholders who would use the climate services, so relevant details were not being discussed. Stakeholder interactions often involved a workshop with presentations while climate service producers rarely interacted in decision-making work environments. Also, when climate service producers asked use-related questions during workshops, oftentimes the stakeholders who used climate services directly were not present. Decision-makers were most commonly upper-level managers or planners who typically only used the output of climate services.

Overall, intermediaries felt they lacked knowledge of how multiple types of information coalesce within climate services. Many intermediaries felt that climate information from the production side of the CSP Spectrum was inadequately communicated to them, hindering their ability to add value to climate services.

Concern about communicating uncertainty was the most commonly identified constraint across the CSP Spectrum. Many climate service producers acknowledged that they focus on the uncertainties within climate services, whereas they perceived that decision-makers want a clear, single number to plug into plans. This perceived conflict between complexity and clarity appeared to persist in most cases, even when climate service users views were incorporated into climate service production processes. Some climate service producers identified this desire for clarity as a decision-maker oversight, and were reluctant to envision a situation where they would feel comfortable providing the perceived or actual clarity desired by decision-makers. Decision-makers looked for guidance from climate service producers, while climate service producers (researchers and those with a scientific background in particular) wanted to assess all angles of uncertainty and make incremental progress on their efforts, not provide decision-making inputs with measures of confidence.

Climate service producers felt uncertainty was hard to explain, especially the amount and types of uncertainty in climate services. For example, one researcher noted that uncertainty surrounding future flooding involved uncertainties in regulation, land use, and climate change adaptation actions (or lack thereof). She provided ranges in climate service outputs that were largely based on unknowns within the human system, but she communicated methodological, climate system, and human system uncertainties equally to decision-makers.

4.3. Stakeholder engagement constraints

Researchers identified most of the stakeholder engagement constraints on climate services production, but they are likely present across the CSP Spectrum. Specifically, researchers identified stakeholder fatigue and disappointment as climate service production constraints. Sometimes the same decision-makers were used in multiple projects and not always to their advantage. Researchers noted that the information produced in some projects was not useful to decision-makers. Sometimes researchers made progress on a methodology which created new research findings, but these new insights did not always produce better information for decision-makers.

Very few climate service producers interviewed for this study (none on the production side of the CSP Spectrum) had undergone training or education focused on stakeholder engagement or knowledge co-production. Researchers were most likely to have a doctorate in the physical sciences (e.g. climatology, forestry, oceanography, hydrology), while a few had a doctorate in an engineering field. For consultants and intermediaries, engineering was the primary discipline of focus. The predominance of educational backgrounds in engineering and the physical sciences persisted across all climate service producers, even amongst communication- and coordination-focused positions.

Stakeholder engagement skills were primarily obtained through direct experience, but direct stakeholder engagement experience did not typically occur until climate service producers moved into mid-career and/or project management stages. Most early-career researchers did not engage with stakeholders. Researchers highlighted the need to publish during early-career stages as the primary reason they were not involved.

Direct experience as a consultant made a noticeable difference in how climate service producers, and their professional cohorts, engaged with stakeholders. Specifically, current and former consultants were primarily focused on communicating with stakeholders and ensuring that climate services aligned with stakeholder project goals. They were less focused on how a climate service created new knowledge and could contribute to peer-reviewed research. Additionally, consultants or former consultants prioritized engaging with stakeholders in decision-making work environments and were quick to use and communicate with boundary organizations, but did not rely on or expect boundary organizations to do all the stakeholder engagement.

Some researchers thought stakeholder engagement was time-consuming. Identifying stakeholders, tailoring information, and stakeholder communication took more time than was desired, allocated, or expected. A few noted that stakeholder engagement took time away from research or proposal writing. All researchers interviewed for this study emphasized regular and prestigious scientific output and the ability to find and secure funding as primary indicators of career success and advancement. Alternatively, when researchers discussed engaging with stakeholders they emphasized their interest in doing so (approximately half of those interviewed) and the need to adhere to funding requirements (almost all of those interviewed). No researchers mentioned stakeholder engagement in relation to professional success or promotion unless it related to the ability to procure funding.

4.4. Funding, professional, or institutional constraints

Climate service producers identified numerous constraints related to shifts in funding and professional roles; and, at least a perceived lack of prestige regarding climate service production. First, researchers noted that the funding landscape had become more project-based over about the past decade. One researcher mentioned that their project-based funding had doubled since 2006 while internal funding remained unchanged; and in other cases, declined. For other researchers, project-based funding had more than doubled.

Many climate service producers noted they were funded entirely on project budgets and that their baseline funding had diminished over

approximately the last fifteen years. As project-based funding increased, researchers were still tasked to complete the same objectives as before, but with a lower proportion of base funding. Less time was allocated for administrative duties, grant writing, and model development which are not typically project-funded activities. Tasks unrelated to projects were sometimes squeezed into project timelines. Many senior-level climate service producers noted that most of their time is spent on project management and grant writing – tasks that can be difficult to fit into project-heavy budgets.

Many climate service producers detailed occasions when they could not provide the necessary information in the amount of time projects specified. Some researchers detailed a process for incrementally improving information over multiple projects, but these improvements were not always provided to decision-makers from previous projects. To avoid this occurring, some climate service producers would conduct multiple projects with the same group of stakeholders (urban decision-makers from a specific community), so that they would eventually receive actionable information. This process appeared to result in actionable information for those stakeholders, however, they eventually wanted to consider more risk types. Unfortunately, researchers continued to focus on the originally identified risks because they were specific to their discipline and research group, and the project was leading to new and publishable insights. Other researchers pursued multiple projects that would benefit from the same or similar methodological processes, or would plan their research first and then try to find projects that tangentially related to their plans.

Lastly, researchers noted that climate services production was not perceived as prestigious. Researchers perceived that stakeholder engagement and climate services development was viewed as applied research that did not lead to the novel insights that fundamental research would produce. One researcher noted a colleague said he only took on climate services work temporarily until basic research funding came through. Others felt it was difficult to produce the scientific results necessary for prestigious publications within a climate service project. Most researchers indicated that climate services development is perceived as necessary in the current funding context, but that it is not perceived as prestigious or particularly helpful for career advancement, though no interview subject stated that they personally felt this way.

4.5. Encountering climate service production constraints

All climate service producers involved in this study encountered some climate service production constraints. When climate service producers overcame constraints, they tended to overcome many of the same constraints repeatedly across multiple projects and contexts. Some constraints were foreseen by climate service producers and time was budgeted to overcome or avoid them. Others were unseen and unplanned for. Addressing unforeseen constraints took time, attention, and resources away from already tight timelines and budgets and were not always effective. For example, one group continually worked with the same stakeholder group on multiple projects, overcoming many constraints related to stakeholder engagement. The climate service producers understood the context of the situation, established trust among stakeholders, and had a firm grasp of what the decision-makers wanted. Sometimes decision-makers did not get the information they needed from a project, but they maintained the relationship and assumed actionable information would come from the next project.[3] This mutual understanding created a continuous relationship that worked across projects which helped climate service producers avoid taking the time to identify stakeholders, lengthy interactions with new stakeholders, and the need to produce both useful information and publishable insights for each project. Also, climate service producers were better able to maintain their publication plans, which did not always fit with project or decision-makers' timelines.

Some decision-makers on these continuous projects were growing fatigued and disappointed, which was recognized by a few researchers and observed by the participant-observer. They wanted to plan for other adaptation risks, but were continually being brought into projects involving one risk-type they had thoroughly planned for. At least one researcher recognized that this was occurring and tried to maintain the relationship by expanding the risks considered and researchers involved, but was having a hard time doing so. The transition towards other adaptation risks was not occurring, because the established relationship was centered around a research group focused on a specific discipline and it was proving difficult to move beyond or diversify that relationship.

Some approaches to lessen or avoid climate service production constraints created consequences within adaptation decision-making processes. For example: some climate service producers focused only on publishable climate service advancements, others produced the same work for multiple projects to save time, and some limited stakeholder engagement to save time. These approaches resulted in un-tailored information for stakeholders. Alternatively, some climate service producers primarily focused on creating actionable information for decision-making and then finding a part of the process that was publishable. This process involved completing many time-consuming and unforeseen tasks like creating new land-use maps, developing or updating indicators, and changing methodologies to align with the contextual details of a situation. While these processes resulted in actionable information for stakeholders, they were done at the cost of publication outputs and project timelines. Each observed or reported attempt to move past climate service production constraints varied in effectiveness and influenced other parts of the adaptation decision-making process.

5. Discussion

The climate service production constraints identified in this study limit the effectiveness of climate services for adaptation decision-making processes. We discuss potential pathways to overcome some of the climate service production constraints identified in this study next.

5.1. Evaluate and reward stakeholder outcomes

More could be done to optimize stakeholder outcomes in climate services production environments. One approach could be to emphasize, evaluate, and measure stakeholder outcomes as indicators of project success or completeness as much as, or more than, scientific output. Scientific output has become quantifiable and enables quick, albeit imperfect evaluation to measure progress, however scientific output does not indicate effectiveness in decision-making (Ford et al., 2013; McNamara et al., 2012). Stakeholder project outcomes are harder to evaluate, but without their evaluation, these outcomes are easy to de-emphasize when compared to something as visible, measurable, and recognizable as scientific output.

Additionally, there should be some recognition across institutions that scientific-output and stakeholder outcomes are not inherently complimentary (McNamara et al., 2012) and may sometimes be difficult to achieve simultaneously. Projects and funding requirements could be expanded to include participatory action research approaches and education and training for how to implement such approaches (Gerger Swartling et al., 2019). A few project funding models like the Mistra Swedish Research Program on Climate, Impact, and Adaptation (Mistra-SWECIA) have increased the duration of some grants to prioritize stakeholder engagement (Hewitt et al., 2013; Jönsson and Gerger Swartling, 2014), and a case from the Swedish forestry sector has used a participatory action research approach to facilitate collaboration and knowledge co-production and emphasize user relevance of knowledge (Gerger Swartling et al., 2019). However, strategic support for boundary work (e.g. work involving boundary partners or knowledge

[3] Decision-maker interactions occurred during participant-observations.

brokers that can act as a mediator or translator between climate service producers and users, employing participatory action researchers and methods, employing a facilitator or mediator, conducting co-designed participatory exercises that involve climate service producers and users) is not yet widely addressed within climate service funding institutions or production environments (Gerger Swartling et al., 2019). Specifically, boundary work that is undertaken jointly and co-initiated, co-designed, and co-produced with multiple stakeholders should be emphasized because it is perceived as more memorable and useful (Gerger Swartling et al., 2019).

If funding moves towards prioritizing and evaluating stakeholder outcomes however, professional incentive structures must also change to reward different types of professional accomplishments (Porter and Dessai, 2017). Without changes across multiple organizational scales (i.e. beyond funding institutions) (O'Brien, 2012; Preston et al., 2015b), contributing to climate services may continue to be valued and perceived as secondary to pursuing currently recognized indicators of success.

5.2. Provide and reward stakeholder engagement, knowledge co-production, and science communication training and education

Stakeholder engagement, knowledge co-production, and science communication training for climate service producers could help alleviate many climate service production constraints. Additionally, the direct experience that current or former consultants bring to climate services production environments could be better recognized, rewarded, and sought-out.

Early-career climate service producers should be better-integrated into climate service dissemination contexts. Excluding early-career climate service producers in knowledge dissemination contexts occurred within this study, and similar findings were reported in Jönsson and Gerger Swartling (2014)[4]. This approach leaves early-career researchers lacking in both training and experience with stakeholders, which may be especially needed in the current funding context (Vaughan et al., 2016).

Additionally, individuals with expertise in science communication and/or knowledge co-production should be considered as potential climate service producers. Increasing interdisciplinarity among climate service producers could lessen some of the knowledge-dissemination and stakeholder engagement constraints observed in this study.

Climate services production could be improved by convening with more types of stakeholders beyond planners and managers. Specifically, analysts and technicians who work directly with climate services could provide more knowledge and experience based on the limitations and usability of climate services. The lack of interaction and engagement from stakeholders who work directly with climate services limits the potential of stakeholder engagement.

5.3. Create flexible climate services and adaptation decision-making processes

Some climate service production constraints will be ever-present, like constraints that concern the constant tide of increasing information about the future (Safford et al., 2017) and the uncertainty inherent in modeling future processes that have yet to occur (Sharifi and Yamagata, 2016; Tonmoy et al., 2014; Tonn, 2000). These constraints may be lessened by increasing the flexibility of climate services and adaptation decision-making processes (Muñoz-Erickson et al., 2017). Research could focus on identifying methods and approaches to update information and models quickly, effectively communicate changes to stakeholders, and develop decision-making processes that are prepared to continually account for new and updated information.

5.4. Recognize, detail, and reduce uncertainty within human systems for decision-making

The inherent uncertainty in modeling a future where humans influence the magnitude of change, is an ever-present aspect of modeling future processes (Sharifi and Yamagata, 2016; Tonmoy et al., 2014; Tonn, 2000). Inherent uncertainty within the human system influences how climate and environmental changes manifest on the landscape and cannot be reconciled through decreases in operational uncertainty (i.e. by creating a better model or having more data) (Tonn, 2000). These realities and limits could be more fully explained (and re-explained) to decision-makers to build a greater understanding of the role that different types of uncertainty play in modeling future processes (Moss, 2016; Tonn, 2000). Additionally, some climate service producers could benefit from an increased understanding of the many ways uncertainty emerges within climate services.

Climate service producers could do more to detail the confidence in their methods and outputs (Moss, 2016), and to discuss the human components of uncertainty to greater detail. Similar to results in this study, Moss (2016) found that some researchers were reluctant to emphasize uncertainties within tools and provide confidence intervals, but those that did more fully agreed on major multidisciplinary and interdisciplinary conclusions.

Alternatively, decision-makers could assign more parameters to their decision-making environment by clearly outlining which scenarios and future options they will consider if more simplicity within climate services is desired. These parameters increase use value uncertainty (i.e. uncertainty caused when estimates or parameters are used in decision-making), but they may also decrease the operational uncertainties of climate services by reducing potential scenarios and options considered within the climate service (Tonn, 2000). Decision-makers can assign these parameters that could add more clarity to climate services tailored to their specific needs.

6. Conclusions

Adaptation efforts continue to increase along with the impacts of climate change. However, adaptation-related policies and regulations typically lack explicit guidance and funding for adaptation implementation (Arnott et al., 2016; Bulkeley, 2010; Porter et al., 2015) which has largely resulted in piecemeal adaptation actions that have predominately occurred in well-resourced areas with motivated actors (Hughes, 2015; Porter et al., 2015) especially if a recent event has been partially attributed to climate change (Mimura et al., 2014).

Climate services have emerged to provide actionable information to guide and support adaptation decision-making efforts. However, the effective production of climate services is limited by constraints. Climate service producers and production environments in Sweden were analyzed in this study to identify these constraints which occurred across climate service production contexts in Sweden, but are not an exhaustive list of all climate service constraints on adaptation.

Some climate service producers in Sweden succeeded at producing and disseminating actionable information for decision-makers despite the existing constraints by prioritizing the creation of actionable information, having a lessened focus or priority on producing high-profile research, producing non-existent data and information outside of their professional scope or discipline, participating in iterative communication and multiple meetings with decision-makers, and working with (but not solely relying on) boundary organizations to engage with stakeholders. Skelton et al. (2017) reported similar findings in the Netherlands – a few climate service producers overcame constraints through great personal motivation and by sacrificing preeminent science to produce actionable information. However, the processes that enable the creation of actionable information for adaptation decision-

[4] Senior scientists were conducting stakeholder interactions to enable more research time for younger researchers.

making are not yet well supported in climate service production environments in Sweden, and likely in other contexts as well (Porter and Dessai, 2017; Skelton et al., 2017). Like Porter et al. (2017) found in the United Kingdom, climate service producers in Sweden are not indifferent to users, and do not ignore them, but instead feel constrained by institutional and systematic priorities and incentives. Further identification of climate services production constraints should focus on identifying generalizable constraints and envisioning pathways to overcome them to avoid becoming hyper-focused on identifying numerous context-specific climate service production constraints.

The creation and dissemination of actionable information for adaptation in Sweden is limited by climate service production environments. To produce widespread actionable information, climate service producers and institutions must change in order to recognize, reward, support, and pursue methods that enable the production and effective dissemination of climate services. However, producing and disseminating robust climate services without adequate funding, staff, guidance, and support for adaptation efforts has not yet yielded, and likely will not yield widespread adaptation actions, because climate services support adaptation implementation, but are not drivers of adaptation implementation. Rather, the production and dissemination of effective climate services must be met with adequate support and guidance to ensure that adaptation efforts are prevalent.

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